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The Convergence Management of Strategic Emerging Industries: Sustainable Design Analysis for Facilitating the Improvement of Innovation Networks

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Abstract: The overall high-end of strategic emerging industries can be effectively promoted by strengthening the inter-industry innovation linkage effect. This paper constructs a strategic emerging industry innovation network based on industry correlation. This paper studies the development trend of the whole network structure and individual network characteristics and analyzes the influence of network structure characteristics on the attribute performance of each industry. The research results are as follows: (i) The innovation network as a whole was in a slight decline trend of low density during the sample investigation period, and the correlation level had great room for improvement. (ii) The high-end equipment manufacturing industry, the new materials industry, and the new-generation information technology industry occupy the center of the network, but their spillover effect on other industries is poor, and some industries even get more innovation benefits. (iii) The innovation network of China's strategic emerging industries has the characteristics of cross-industry clustering, and the linkage effect between plates is insufficient, showing the characteristics of the "reflexivity" aggregation subgroup. (iv) The unreasonable connection mode of strategic emerging industries' innovation network leads to the improvement of the centrality degree, which is not conducive to the innovation output of the industry. However, innovation output can be positively affected, to a certain extent, by improving the betweenness and closeness of the industries in the network.

Keywords: strategic emerging industries; innovation networks; social network analysis; industry association; industry distance

1. Introduction

With the rapid evolution of a new round of scientific and technological revolution and industrial transformation around the world, the global economic pattern has been reshaped. The United States, Germany, Japan, and other developed countries have laid out strategic emerging industries, accelerated cutting-edge technology research, and promoted cross-industry integration, which is both an opportunity and a challenge for China to enhance its position in the global value chain. China's economy has shifted from high-speed growth to high-quality development stage, and accelerating this adjustment and optimization of industrial structure is an important task at this stage. Strategic emerging industries are the bellwether leading the development of science, technology, and social progress. In November 2019, the national development and reform commission of China issued the guide catalogue for industrial restructuring (the 2019 edition), which pointed out the direction of industrial development in favor of strategic emerging industries and gave priority to the high-quality development of manufacturing. On the one hand, strategic emerging industries have been actively cultivated and vigorously developed to enhance new drivers of industrial development. On the other hand, to promote the transformation of industries to digitalization, networking, and intelligence through the efficient integration of traditional industries and emerging industries. Based on the theory of industrial correlation, there are input–output correlation and supply–demand correlation between the upstream and downstream of the industrial chain. Strategic emerging industries are an important force to promote industrial transformation and upgrading. Strengthening the innovation linkage effect among strategic emerging industries can effectively promote the high-end of the industry as a whole. Therefore, it is of great theoretical and practical significance to study the innovation network of strategic emerging industries to achieve high-quality development of manufacturing industry. This is conducive to promoting industrial integration, optimizing the allocation of stock resources, and expanding the supply of high-quality incremental.

Both the US reindustrialization strategy and Germany's industry 4.0 are based on Schumpeter's innovation theory, which holds that economic growth and economic development are fundamentally different. Economic growth means that over a sustained period of time, the economy will not be disrupted. The development is from the internal change, he thinks the industrial mutation is the revolution of the economic structure. China is in the stage of high-quality development of economic structure, and the technology connection between industries can effectively drive industrial integration. Industrial mutation is the quantitative result of industrial integration and accumulation. Therefore, efficient industrial integration can promote high-quality economic development. From a more microscopic perspective, input–output tables can reflect the inter-industry demand relationships that make up industries. It contains the direct or indirect, obvious or hidden technical and economic connections between departments in the actual production process, forming the inter-industry network based on product demand. When the product innovation quality of a certain industry is improved, the product innovation quality of the industry directly or indirectly related to the network will be actively or passively improved, thus promoting the continuous improvement of the overall innovation network level. Therefore, based on product demand correlation, an inter-industry innovation network can be formed by driving technology integration in order to realize industrial integration and trigger high-quality economic development. Strategic emerging industries are the pillar industries to promote economic development. The Chinese government has identified nine major industries as strategic emerging industries according to its national conditions and global development status, with the high-end equipment manufacturing industry as the core, the new generation of information technology industry as the support, and the energy conservation and environmental protection industry as the pilot. Other industries are the driving forces of the strategic industrial pattern—nine industries keep pace with each other and infiltrate each other, trying to indirectly promote the development of other industries through the development of one industry. China has not lagged behind in emerging areas such as cloud computing, big data, the Internet of things, and artificial intelligence, successfully spawning local Internet giants such as Alibaba and Tencent. Moreover, with the official issuance of 5G licenses, China's 5G is in the trend of running or leading in some places, and companies like Huawei Haith, which are comparable to the international first-class level, have emerged. However, in the traditional ICT industry (such as the design and manufacturing of chips, semiconductors, integrated circuits, etc.), there is a large external dependence, and the self-sufficiency rate only reaches about 10%. Therefore, through the innovation of the high-end equipment manufacturing industry, new materials, and other industries in the manufacturing of intelligent key basic components and electronic special materials, the efficient development of ICT industry can be accelerated.

The knowledge-intensive characteristics of strategic emerging industries determine that they need multi-subject participation and multi-factor coordination. Studies on innovation participants in strategic emerging industries [1], innovation efficiency [2,3] and influencing factors [4], policy mechanisms [5], and technology specialization dynamics [6] have received extensive attention. Innovation network is a dynamic and open complex system with multiple participants. It is a networked organizational form developed by enterprise alliance [7], industry-university-research cooperation [8], and industrial association [9]. The interactive decision-making of participants in the network is influenced by such factors as knowledge flow [10], information system [11], and degree of cooperation and openness [12]. Lin et al. (2018) conducted a simulation analysis of scale-free network based on the game model and studied innovation behavior according to the diffusion of innovation state in network [13]. Shi (2019) constructed an innovation network evolution model and conducted numerical simulation analysis based on inter-organizational dependency [14]. Industry correlation begins with technology convergence. Based on the theory of industry correlation, Pan et al. (2011) calculated the technology spillover matrix among 35 industrial sectors in China and its impact on productivity based on China's input–output table [15]. Xing et al. (2011) studied the degree of convergence of China's ICT industry from the perspectives of supply-demand relationship and substitution relationship based on the input–output table [16]. Focusing on the innovation networks of strategic emerging industries, Zhang et al. (2018) analyzed the formation process and evolution mechanisms of innovation networks of strategic emerging industries, constructed the evolution model of a binary attribute innovation network, and conducted simulation analysis with new energy vehicles as an example [17]. Song et al. (2019) proposed a new Schumpeterian-innovation development channel for the evolution of strategic emerging industries and extended the structure of R&D cooperation network to three embedded models of "relationship, structure, and location" [18]. Liu et al. (2018) analyzed the evolution process of innovation network among strategic emerging industries, academic institutions and government based on evolutionary game theory [19].

From the perspective of research methods, in addition to the simulation analysis method of evolutionary game adopted by the above scholars, social network analysis is an interdisciplinary analysis method based on "relational data" to study relational patterns with graph theory tools and algebraic models [20], which is widely used to study the characteristics of network structure. Su et al. (2018) determined the relationship matrix by VAR Granger causal relation test and studied the regional innovation association network problem by using the method of social network analysis [21]. Dong et al. (2013) built an industrial structure network model based on the input–output table and analyzed the stage characteristics of industrial structure [22]. Su et al. (2019) analyzed the structural characteristics of the spatial correlation network and discussed the main factors influencing the correlation strength of the spatial correlation network using the quadratic distribution method [23]. Liu et al. (2019) constructed the spatial network relationship matrix of China's regional economic growth based on the ideas of gravity model and studied the network structure characteristics using the social network analysis method [24]. In addition, fuzzy logic is an important research method, and Zadeh (1996) is the founder of the field of fuzzy logic and the main contributor to the development of the field of fuzzy logic over the past 50 years [25]. At present, many scholars use fuzzy logic to study the system control problems. For example, Piancastelli et al. (2011) studied the fuzzy control system for recovery direction after spinning in the manufacturer's equipment, so as to improve the safety of the vehicle [26]. Yin and Li (2018) studied the matching problem of green technology innovation system of industry-university-research cooperation by using fuzzy logic method and pointed out that fuzzy logic method has important practical value [27]. Piancastelli et al. (2011) introduced the application of fuzzy logic in the controller design of industrial buildings and discussed the advantages of the method and its application in control engineering [28]. Mamdani (2011) studied the fuzzy anti-skid control system of high-performance motorcycles and applied it to practice [29]. Wicher et al. (2019) studied a method of paste preference planning for aggregate sustainability performance evaluation and conducted a comprehensive sustainability performance evaluation [30].

Many scholars have studied strategic emerging industries and innovation networks extensively, and the existing literature has laid a solid theoretical foundation for the research of this paper. However, research on innovation network of strategic emerging industries is still in the development stage, especially on the overall performance and individual characteristics of innovation network of strategic emerging industries based on relational data rather than attribute data, which is relatively scarce. The only studies on industrial correlation are based on the correlation matrix determined by the input–output relationship, which cannot accurately construct the inter-industry innovation network. Therefore, in order to make up for the shortcomings of existing studies, this paper takes 26 industries supported by strategic emerging industries as the research objects and constructs the correlation matrix of strategic emerging industries. The method of social network analysis is used to analyze the overall network characteristics and evolution trend as well as individual network characteristics. The influence of structural characteristics on the innovation attribute data is further analyzed.

The innovation of this paper is as follows: (1) The idea of gravity model is extended to the strategic emerging industry innovation network correlation matrix. Based on the input–output table, the variable of industry distance is introduced, and the R&D intensity and personnel input are taken as supplementary variables to examine the "quality" of innovation, so as to ensure that the marketability spillover, relevance spillover and knowledge spillover of technology between industries are simultaneously considered. (2) Deconstruct strategic emerging industries into different sectors and analyze the innovation network correlation of strategic emerging industries from new dimensions. (3) On the basis of constructing an innovative network based on relational data, the effect of network structure on attribute performance of various industries is further examined.

The structural arrangement of this paper is as follows. In Section 2, the method of social network analysis—the gravity model—is adopted to determine the strategic emerging industry innovation network correlation. In Section 3, the empirical research includes the analysis of the innovation network from the three dimensions of the overall network characteristics and evolution trend, the individual network characteristics and the block model. The effect of the individual network characteristics of the innovation network on the performance of industry attributes is further analyzed. The empirical results are summarized and discussed in Section 4. Section 5 summarizes the research conclusion and enlightenment of this paper and points out the shortcomings of this paper.

2. Study Design

2.1. Study Methods

Social network analysis uses graph theory tools and algebraic models to study relational patterns based on "relational data." Compared with the traditional methods of statistics and simulation, its core emphasizes the dynamic effect of the subjective initiative of node "people" on the relationship change. Moreover, it disregards the assumption of independence and considers that all nodes are potentially dependent. The distinction between symmetry and asymmetry of relationships is more applicable to the study of networks formed by complex relationships, which is also in line with the sustainable network characteristics of innovation in strategic emerging industries. First, strategic emerging industries as nodes are highly dynamic. Inter-industry innovation development is influenced by international environment and policy making and can adjust its innovation development direction according to the innovation development status of other industries. Second, based on the input–output table, it can be seen that there are technological correlations among industries, and the innovation relationship is of complex network. There is a symmetrical relationship between related industries and an asymmetrical relationship between the upstream and downstream industries of the industrial chain. Finally, we should study the strategic emerging industry innovation sustainable network from an overall perspective. Social network analysis is based on the network as a whole rather than a single event to study the nodes. Therefore, it is very appropriate to use social network analysis to study the sustainable network of strategic emerging industry innovation. In order to clearly demonstrate the social network analysis method used in this study, the definition of letter symbols is further summarized, as shown in Appendix A.

2.1.1. Determination of Innovative Network Association

Social network analysis can effectively reflect the relationship between actors rather than attributes, and the VAR model is very sensitive to the selection of lag order [31]. The inter-industry correlation network built based on the input–output table can only describe the network correlation between product output and demand of each department and only considers the marketability spillover effect of inter-industry technology. Moreover, it is impossible to investigate the inter-industry correlation spillover effect and knowledge spillover effect of technology [15], thus describing the inter-industry technology correlation network lacking accuracy [32]. The gravity model can make up for the shortcomings of the two methods.

The gravity model has been widely used in geography, economics, management, and other research fields. The model argues that the gravitational relationship between two economies is proportional to "mass" and inversely proportional to obstacles such as "distance." By using the gravity model, research on non-spatial factor flows such as academic migration [33], capital flow of real economy and virtual economy [34], government subsidy and enterprise total factor productivity [35], and inter-industry gravity [36,37] has expanded. In terms of the flow of innovation elements between industries, the technological and economic links between different industries provide the possibility of technological links between industries. Resource potential differences provide a driving force for inter-industry technology flows. Industry distance increases the technical barrier and impedes the absorption capacity of technology between industries. At the same time, the strategic emerging industry innovation network relational matrix constructed by the gravity model can comprehensively consider the interindustry technology's marketability spillover, relevance spillover, and knowledge spillover. Moreover, it can introduce innovative resources such as R&D investment into the production function, which is more in line with our research. Therefore, the idea of the gravity model was introduced, and innovation output was taken as the "quality" variable affecting inter-industry innovation gravity, with reference to the setting standards in literature [31] and [38]. R&D intensity and personnel input are introduced as supplementary variables to measure the innovation "quality" of various industries [32,38], and the inter-industry innovation correlation matrix of strategic emerging industries is established as follows.

$$Y_{ij} = K_{ij}\frac{\sqrt[3]{P_i \times E_i \times G_i}\sqrt[3]{P_j \times E_j \times G_j}}{D^r{}_{ij}}, K_{ij} = \frac{E_i}{E_i + E_j}, \tag{1}$$

where Y_{ij} represents the innovation attraction between industry i and industry j. E_i and E_j represent the innovation output of i and j industries, as measured by the number of patent applications. P_i and P_j represent the input of innovative personnel, as measured by the equivalent of full time R&D personnel. G_i and G_j represent the intensity of innovation capital input, as measured by the ratio of internal expenditure of R&D expenditure to main business revenue. K_{ij} represents the contribution rate of industry i in the innovation association between industry ij. D_{ij} is the industry distance, and r is the friction coefficient [39,40].

As for the measurement of industry distance, this paper uses the input–output table to calculate it using the method of industrial chain position difference [41]. First, the basic identity of the input–output table is introduced as follows:

$$X_i = F_i + Z_i, \tag{2}$$

where X_i is the total output of the industry i; F_i is the total amount of the industry i flowing directly to the final consumer and capital formation, and Z_i is the part consumed by other industries as intermediate inputs in the output of the industry i. In N national economic systems, the above equation can be expressed as:

$$X_i = \underbrace{F_i}_{\text{Direct consumption}} + \underbrace{\sum_{j=1}^{N} a_{ij}F_j + \sum_{j=1}^{N}\sum_{k=1}^{N} a_{ik}a_{kj}F_j + \sum_{j=1}^{N}\sum_{k=1}^{N}\sum_{l=1}^{N} a_{il}a_{lk}a_{kj}F_j + \ldots}_{\text{Indirect consuming}}, \tag{3}$$

where a_{ij} is the direct consumption coefficient, which represents the value of goods or services consumed by the total output per unit of industry j. That is, the value of the goods or services of the product i sector directly consumed in the production and operation of the industry. Based on the product consumption relationship between the above industries, the weighted average position measurement method of each industry in the industrial chain can be obtained [42].

$$V_i = \frac{F + 2AF + 3A^2F + 4A^3F + \ldots}{X_i} = \frac{(I - A)^{-2}F}{X_i}, \tag{4}$$

where I represents the identity matrix, and the direct consumption coefficient a_{ij} constitutes the matrix A. F is a matrix made up of F_i. As the input of industry i is farther upstream of the industrial chain, it takes up more weight, so that $V_i \geq 1$. If the inverse treatment is taken for V_i, the relative position of i industry at the downstream of the industrial chain can be obtained [43]. Denoted as U_i, and $U_i \in [0, 1]$, the larger the value, the more downstream of the industrial chain. The industry distance D_{ij} is represented by the absolute difference of the downstream position of the industrial chain of i and j, and $D_{ij} \in [0, 1]$, that is:

$$D_{ij} = \left| U_i - U_j \right|. \tag{5}$$

According to model (1), the correlation matrix can be calculated. The average value of each row of the matrix is taken as the threshold value, and the elements higher than the average value are denoted as 1. This means that the industry has a correlation with the innovation output of the industry. Otherwise, it is denoted as 0, indicating that there is no correlation [24,44]. Finally, the multi-valued matrix is transformed into a binary matrix.

2.1.2. Network Characteristic Index

(1) The overall characteristics of strategic emerging industries innovation network. In this paper, the overall network density, network correlation, network grade and network efficiency are selected to describe the characteristics of the network. The overall network density can reflect the close degree of innovation correlation between industries in the network. The higher the density, the higher the correlation degree of innovation output between industries. For a directed network of scale N, the total number of relationships that the network is likely to reach is $N(N-1)$, and the actual number of relationships is n, then the overall density of the network is as follows:

$$\rho = \frac{n}{N(N-1)}. \tag{6}$$

Network correlation reflects the vulnerability and robustness of the overall network. High correlation means that any two industries in the network can be directly or indirectly accessible. Similarly, for a directed network of scale N, if m represents the number of unreachable point pairs in the network, the correlation degree is as follows:

$$R = 1 - \left[\frac{m}{N(N-1)/2} \right]. \tag{7}$$

The degree of network hierarchy represents the degree of asymmetric accessibility between industries and measures the dominant position of industries in the network. The higher the degree, the more hierarchical the overall network structure. The greater the difference in power between industries, the more industries are subordinate and marginal. If S represents the logarithm of points that are symmetrically reachable in the whole network, $\max(S)$ represents the logarithm of points that i can reach j or j can reach i. Then, the calculation formula of network grade is as follows:

$$GH = 1 - \frac{S}{\max(S)}. \tag{8}$$

Network efficiency refers to the extent to which the network has redundant lines. The lower the network efficiency, the more spillover channels of inter-industry innovation output, and the easier it is to promote the flow of inter-industry innovation factors through this network. If e_k represents the number of redundant lines in component k, $\max(e_k)$ represents the number of lines in component k that are most likely to be redundant. We can get the number of redundant lines in the whole network E and the maximum possible number of redundant lines $\max(E)$. In general, there is only one component for the associated network, and the efficiency of the overall network is as follows:

$$GE = 1 - \frac{E}{\max(E)}. \tag{9}$$

(2) Analysis on the individual centrality of strategic emerging industry innovation network. Social network analysis mainly includes degree centrality, betweenness and closeness. The higher the degree of centrality, the closer the industry is connected with other industries in the innovation association network, and therefore the more central it is [45]. In a directed network, absolute degree centrality is also known as "local centrality," which is divided into point-in degree and point-out degree, indicating the number of relations directly received and sent by the industry. In order to enhance the comparability, the relative centrality is also calculated, and the difference between bidirectional strong connection and unidirectional weak connection is not considered.

Betweenness measures the extent to which the actor is in the middle of other point pairs. The higher the degree of betweenness, the greater the control ability of the industry over resources, and the greater the intermediary bridge between the other two industries. Let the shortcut number between point j and point k be g_{jk}, point i is the third point passing between point j and point k, and the shortcut number is $g_{jk}(i)$. Then, the ability of point i to control the communication between point j and point k is $b_{jk}(i) = g_{jk}(i)/g_{jk}$. Then, the relative mediation center after all points are added is as follows:

$$C_{RBi} = \frac{2\sum_j^n \sum_k^n b_{jk}(i)}{n^2 - 3n + 2} \; j \neq k \neq i, j < k. \tag{10}$$

Closeness measures the extent to which an actor is not controlled by another actor. The shorter the distance between one industry and others, the better the exchange of information. For a network of scale N, d_{ij} is the shortcut distance between point i and point j, then the closeness is as follows:

$$C_{RPi} = \frac{N-1}{\sum\limits_{j=1}^{n} d_{ij}}. \tag{11}$$

(3) Strategic emerging industry innovation network block model analysis. The block model focuses on the overall structure of the network and can deconstruct a strategic emerging industry from a new dimension. Based on the overall performance of the network, it is re-structured in different sectors, so that the innovation exchange between each sector is no longer limited to the strategic emerging industries. Based on previous literature [46–48], this paper divides the roles of sectors in inter-industry innovation association network into four categories.

The first category is the main beneficiary role. The industry of this sector not only receives the relationship between the industries of other sectors but also has spillover behavior to the industries of other sectors. At the same time, the communication within the plate is also relatively frequent, but the number of relations received from other plates is more than that spilled out.

The second category is the primary overflow role. The industry overflow relation of this kind of plate to other plates is obviously more than the relation receiving from other plates and the relation within plates.

The third kind of plate is the two-way overflow role. The industry of this kind of plate sends out the relationship to both the inside and outside of the plate, but seldom receives the relationship of other plates.

The fourth kind of plate is broker role, which not only accepts the overflow of other plates but also flows to other plates, and the internal relationship is more balanced.

The innovation network of strategic emerging industries is analyzed from the three dimensions of overall network characteristics, individual centrality, and block model. To further study the effect of individual network characteristics on attribute performance of various industries, the research framework of this paper is shown in Figure 1.

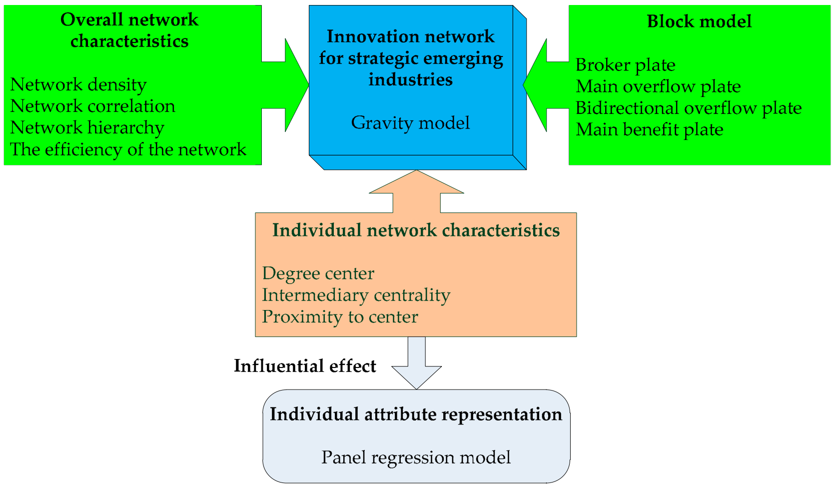

Figure 1. Research framework.

2.2. Study Data

According to the classification of strategic emerging industries (2018) released by the national bureau of statistics, the classification is based on GB/T 4754-2017, which reclassifies activities that meet the requirements. This paper follows the principles of scientificity, uniqueness. and large caliber [49–51] and classifies the four-level industry codes according to the main degree and degree of inclusion involved in the industry. Finally, 26 industries were selected as the research objects of this paper, as shown in Table 1. The 26 industries selected in this paper come from seven major strategic emerging industries in China, involving mining, manufacturing, power generation, thermal power, and gas and water production and supply. The research samples are the main industrial industries in China, and the environmental pollution problem mainly comes from industrial pollution. Therefore, the research on the innovation network of strategic emerging industries in the industrial industry can effectively realize the strategic goal of green development on the whole. Specifically, the energy conservation and environmental protection industry, the new material industry, and the new energy industry include six energy-intensive industries and the mining industry. In the process of energy production and consumption, water pollution, air pollution, and other environmental problems are easily caused. The innovative development of other industries, such as high-end equipment manufacturing, can drive industries with high energy consumption and high pollution to improve mining technology and energy efficiency technically, and gradually eliminate backward production capacity. At the same time, the development of the new generation of information technology industry not only establishes a full coverage of environmental testing network, but also realizes a sustainable production and consumption pattern. Therefore, this study selects these 26 industries as samples to study the innovation network of strategic emerging industries. This can promote green and sustainable development of the industry as a whole. In this paper, 2013 is selected as the time node, and the data are mainly from the statistical yearbook of China, statistical yearbook of science and technology of China and national input–output table of 2017 from 2013–2018.

Table 1. Twenty-six industry classifications.

Serial Number	Sector	Industry	Serial Number	Sector	Industry
B06	Coal mining and washing industry		C26	Chemical raw materials and chemical products manufacturing	
B07	Oil and gas extraction	Energy conservation and environmental protection industry	C28	Chemical fiber manufacturing	New material industry
B08	Ferrous metal mining industry		C29	Rubber and plastic products	
B09	Nonferrous metal mining industry		C30	Non-metallic mineral products industry	
B10	Non-metallic mining industry		C31	Ferrous metal smelting and rolling industry	
C25	Petrochemical, coking and nuclear fuel processing industries		C32	Non - ferrous metal smelting and rolling processing industry	
D46	General equipment manufacturing		C33	Metal products industry	
C34	Special equipment manufacturing		C36	Automobile manufacturing	New energy automobile industry
C35	The production and supply of water	High-end equipment manufacturing industry	D44	Power and heat production and supply industries	New energy industry
C37	Manufacturing of railway, shipping, aerospace and other transport equipment		C39	Computers, communications and other electronics	New generation of information technology industry
C38	Electrical machinery and equipment manufacturing		C13	Agricultural and sideline food processing	
C40	Instrument manufacturing		C14	Food manufacturing	Biological industry
C43	Metal products, machinery and equipment repair industry		C27	Pharmaceutical manufacturing	

3. Empirical Research

3.1. Overall Network Characteristics and Evolution Trend

Based on the gravity model, this paper constructs the innovation network matrix of strategic emerging industries. The matrix conforms to the relationship between product consumption and output of the corresponding industry sectors in the input–output table. In order to clearly and intuitively show the specific form of innovation network structure, Netdraw, a UCINET visualization tool, was used to draw the industry-related innovation directed network graph. As shown in Figure 2, the node size in the figure represents the centrality degree of the industry. It can be found that the inter-industry innovation correlation of strategic emerging industries has obvious network characteristics, but the inter-industry heterogeneity is significant. Figures 3 and 4 describe the dynamic change trend of network density, network efficiency and network grade of the samples during the investigation period from 2013 to 2018.

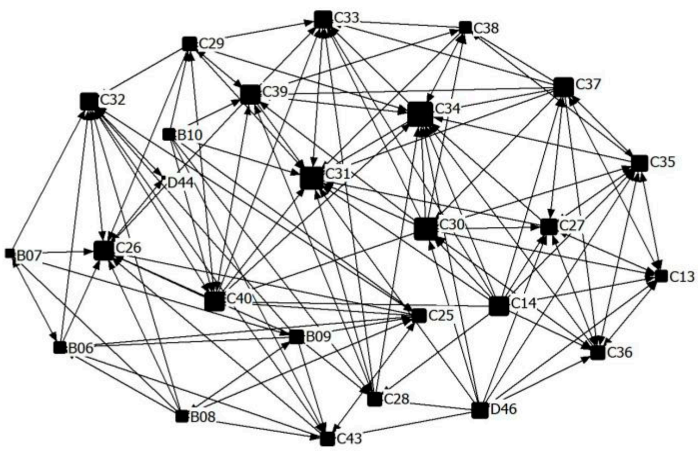

Figure 2. Innovation network of strategic emerging industries in 2018.

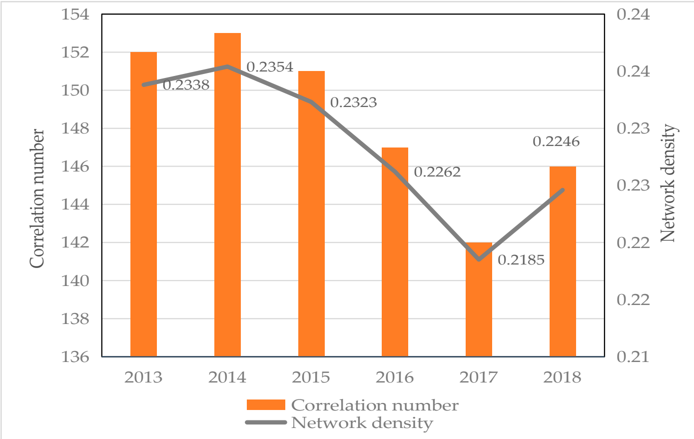

Figure 3. Overall network correlation number and network density.

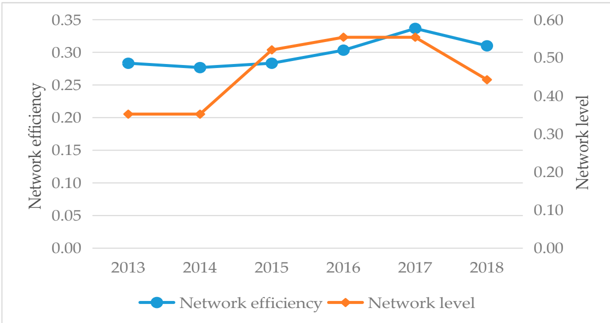

Figure 4. Overall network efficiency and network level.

3.2. Individual Network Characteristics

After analyzing the characteristics of the whole network, this paper calculates the centrality of individuals in the whole network. This paper investigates the specific performance and status of each industry in the overall network from the following three perspectives: degree centrality, betweenness, and closeness. The measurement results are shown in Table 2.

Table 2. Analysis of the centrality of innovation network in strategic emerging industries in 2018.

Industry	Centrality Degree					Betweenness		Closeness	
	In-Degree	Out-Degree	Number of Related Industries	Centrality	Ranking	Centrality	Ranking	Centrality	Ranking
B06	5	3	7	28.000	21	0.304	21	46.296	22
B07	3	4	5	20.000	25	0.000	25	40.323	25
B08	1	7	7	28.000	22	0.304	22	46.296	23
B09	2	8	8	32.000	17	3.320	13	51.020	17
B10	0	7	7	28.000	20	1.968	14	52.083	15
C13	7	4	7	28.000	24	0.145	24	45.455	24
C14	0	11	11	44.000	8	3.726	11	56.818	10
C25	5	5	8	32.000	18	1.875	16	52.083	16
C26	11	2	11	44.000	4	13.079	1	58.140	6
C27	7	7	9	36.000	13	0.462	19	49.020	18
C28	5	4	8	32.000	15	5.374	8	58.140	7
C29	3	7	8	32.000	16	3.584	12	58.140	9
C30	6	10	13	52.000	2	4.473	10	59.524	5
C31	13	1	13	52.000	3	4.859	9	60.976	4
C32	10	5	10	40.000	9	6.437	6	54.348	12
C33	10	1	10	40.000	10	1.281	17	55.556	11
C34	12	4	14	56.000	1	6.240	7	62.50	3
C35	7	7	9	36.000	12	0.658	18	48.077	20
C36	7	5	8	32.000	19	0.210	23	47.170	21
C37	4	10	11	44.000	7	1.912	15	53.191	14

Table 2. *Cont.*

Industry	Centrality Degree					Betweenness		Closeness	
	In-Degree	Out-Degree	Number of Related Industries	Centrality	Ranking	Centrality	Ranking	Centrality	Ranking
C38	5	4	7	28.000	23	0.310	20	49.020	19
C39	8	8	11	44.000	6	8.701	4	64.103	2
C40	7	7	11	44.000	5	12.512	2	64.103	1
C43	6	4	8	32.000	14	8.171	5	54.348	13
D44	2	2	2	8.000	26	0.000	26	37.879	26
D46	0	9	9	36.00	11	9.097	3	58.140	8
Mean value	5.615	5.615	8.923	35.692	-	3.808	-	53.183	-

3.3. *Block Model*

In this paper, the CONCOR module in Ucinet software is adopted to conduct clustering research, which can more systematically analyze the clustering correlation of different industries [52]. In the study, the maximum segmentation depth was 2, and the concentration standard was 0.2. The 26 industries are divided into four sectors, and the spillovers between and within the sectors are shown in Table 3. Plate I includes B06, B07, B08, B09, C43, D44, C25, C26, C32, mainly concentrating in the energy conservation and environmental protection industry and new energy industry. Plate II includea C29, C40, B10, involving the energy conservation and environmental protection industry, high-end equipment manufacturing industry and new materials of three different industries. Plate III includea C14, C37 and C13, C30, C27, C35, C36, D46, containing all of the biological industry, new energy automotive industry. Plate IV includea C38, c 33, C34, C28, C39, C31, involving new materials industry, a new generation of information technology industry. At the same time, each sector contains high-end equipment manufacturing.

Table 3. Correlation effect analysis of strategic emerging industries innovation correlation plates.

Innovation Related Plate	Number of Members	Reception Relation Number		Emission Relation Number		Expected Internal Relationship Ratio	Actual Internal Relationship Ratio	Plate Type
		Plate Internal	Plate External	Plate Internal	Plate External			
Plate I	9	37	8	37	3	32.0	92.5	Broker
Plate II	3	4	6	4	17	8.0	19.0	Main overflow
Plate III	8	38	0	38	25	28.0	60.3	Bidirectional overflow
Plate IV	6	19	34	19	3	20.0	86.4	Main benefit

In 2018, the overall network density was 0.2246. If the density at any position of the four plates is greater than the overall density, the position is 1- block. It indicates that the innovation correlation has a central tendency among the plates, otherwise it is 0- plate. The network density matrix and image matrix are shown in Table 4. Figure 5 visually describes the correlation between and within plates as a whole.

Table 4. Network density matrix and image matrix.

Innovation Related Plate	Density Matrix				Like the Matrix			
	Plate I	Plate II	Plate III	Plate IV	Plate I	Plate II	Plate III	Plate IV
Plate I	0.514	0.074	0.000	0.019	1	0	0	0
Plate II	0.222	0.667	0.000	0.611	0	1	0	1
Plate III	0.014	0.083	0.679	0.458	0	0	1	1
Plate IV	0.019	0.111	0.000	0.633	0	0	0	1

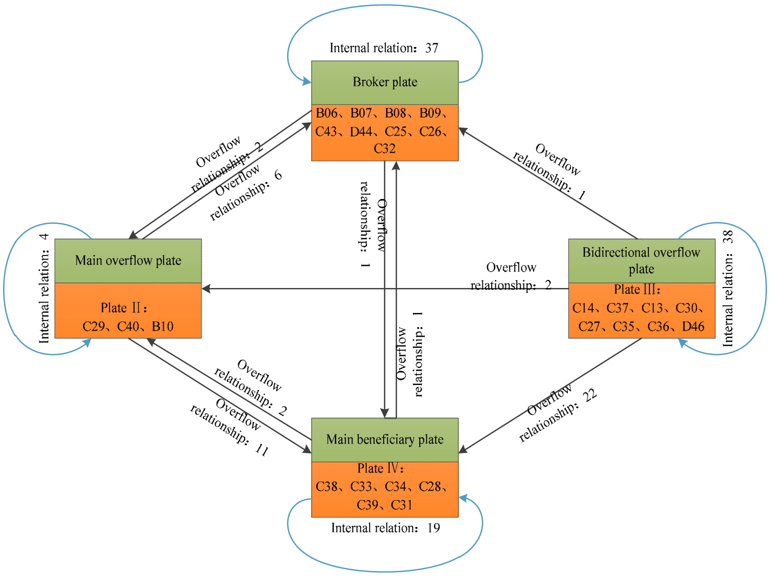

Figure 5. Correlation among the four sectors of strategic emerging industry innovation network

3.4. The Effect of Network Structure Characteristics on Industry Attributes

The structural characteristics of the innovation network are determined by the attribute data of each industry. In turn, the characteristics of the innovative network structure will affect the attribute performance of various industries [44]. Based on the analysis of the characteristics of innovation network structure in strategic emerging industries, the influence of the characteristics on the attribute data of innovation output in various industries is studied. Therefore, the innovation output data of various industries are the explained variables, and the degree centrality, betweenness and closeness of individual network characteristics are the explanatory variables. The panel regression model is established. Due to the different nature of the industry, government support and the proportion of state-owned economy were selected as control variables. The regression results are shown in Table 5.

Table 5. Panel regression results of network characteristics and innovation outputs.

	Model1	**Model2**	**Model3**
Constant term	8.260 ***(0.748)	7.105 ***(0.439)	4.342 ***(1.557)
Centrality degree	−0.319 *(0.172)	-	-
Betweenness	-	0.002(0.010)	-
Closeness	-	-	0.702 *(0.378)
Level of government support	−0.330 ***(0.059)	−0.330 ***(0.060)	−0.307 ***(0.060)
Proportion of state economy	−0.565 ***(0.175)	−0.578 ***(0.183)	−0.638 ***(0.179)
Wald	53.08 ***	48.54 ***	53.04 ***
R^2	0.085	0.120	0.143
Hausman	3.24	1.32	0.99
FE/RE	RE	RE	RE

Note: "*", "**", and "***" mean significant at the level of 10%, 5%, and 1%, respectively; - means no data.

4. Results and Discussions

4.1. Analysis of the Characteristics and Evolution Trend of the Whole Network

As can be seen from Figures 3 and 4, the analysis result of the characteristics and evolution trend can be seen in Table 6.

Table 6. The analysis result of the characteristics and evolution trend.

Analysis Indicators	Analysis Result
Network correlation number	With a large gap between the maximum possible correlation number, it dropped to the lowest in 2017 and rose in 2018.
Network density	It peaked in 2014, bottomed out in 2017, and rebounded in 2018.
Network correlation	During the study period, all were 1.
Network hierarchy	The trend is rising year by year, peaking in 2016 and 2017 and decreasing in 2018.
The efficiency of the network	The trend increased year by year, reaching the highest in 2017, and the network stability was the worst.
Overall innovation network trends	In the innovation network, there are no isolated industries among strategic emerging industries, and the innovation output between industries has industry correlation and spillover effect. However, inter-industry innovation network connectivity is not high, the overall trend is declining.

As can be seen from Figure 3, the inter-industry innovation network is not highly correlated, and the maximum possible correlation number is 650. However, there were only 153 at most in 2014, and by 2017, there were 142. Similarly, the network density reached only 0.2354 at the peak and a low of 0.2185 in 2017. Although it has picked up in 2018, there is still a lot of room for growth. The reason for the fluctuation in network density may be the adjustment of national industrial policy. As a result, the overall network density development trend turned in 2017. In order to realize the strategic goal of manufacturing power, the core technology breakthrough in key areas was achieved in the reorganization of industrial structure of urban agglomeration. At the same time, in order to align "made in China 2025", the national development and reform commission (NDRC) adheres to the principle of industrial agglomeration and creates the source of strategic emerging industries. Under the continuous promotion of industrial policies, the innovation linkage between various industries has been further strengthened. During the sample investigation period, the network correlation degree is 1. It indicates that there are no isolated industries among strategic emerging industries in the innovation network, and the innovation output between industries has industry correlation and spillover effect.

As can be seen from Figure 4, the fluctuation trend of network grade and network efficiency is similar to that of network density, and both of them showed a turning point in 2017. The network's isoparacters peaked at 0.55 in 2016 and 2017 and dropped sharply in 2018. This indicates that the hierarchical structure of heavily correlated innovation among industries has been broken with the implementation of industrial policies, but it has not returned to the low-grade state in 2013. The status of each industry in the innovation network is still quite different, and the driving role of inter-industry innovation correlation needs to be further enhanced. Network efficiency increased year by year, reaching a peak of 0.34 in 2017. This indicates that there are fewer redundant lines in the network and the overall network structure is not stable. With the adjustment of industrial policy, it decreased in 2018. There are more channels to link innovation between industries, with slightly more stability, but there is still a lot of room for improvement.

4.2. Analysis of Individual Network Characteristics

It can be seen from the results in Table 2, the analysis result of individual network characteristics can be seen in Table 7.

Table 7. The analysis result of individual network characteristics.

Analysis Indicators	Analysis Result
Centrality degree	Although the overall performance of innovation among industries is relatively balanced, the level of correlation is not high.
Betweenness	C26, C40, D46, C39, etc. are at the core of network "intermediary" and "bridge" and have strong control over other industries in the innovation network.
Closeness	C40, C39, C34, C31, C30 and other industries have a short "distance" from other industries in the network.
Individual network characteristics of the overall performance	The performance of each industry in the three dimensions of individual centrality varies little. High-end equipment manufacturing industry, new materials industry, new generation of information technology industry occupy the center of the network.

It can be seen from the results in Table 7 that, from the perspective of centrality degree, there is a serious imbalance in the performance of point-in degree and point-out degree in various industries, especially in the top three (C31, C34, and C26) of the high-end equipment manufacturing and new materials industries. The inclination of national industrial innovation policy is aimed at promoting the high-quality development of other industries with pillar industries. However, these industries did not have a strong spillover effect in terms of innovation correlation. Instead, the rest of the industry has benefited from more innovation. Non-metallic mining, food manufacturing, and water production and supply industries, which prefer basic industries, show strong spillover effects. Without considering the degree of correlation, the mean value of dot centrality degree is 35.692, among which 13 industries are higher than the mean value, accounting for 50% of the total. High-end equipment manufacturing industry, new materials industry and new generation of information technology industry account for the majority, indicating that the overall correlation between industries is relatively balanced. However, it can also be seen that the C34, which ranks the first in the high-end equipment manufacturing industry, has a great difference in the performance of the D44 center of the new energy industry. In addition, the center degree of C34, which ranks the first, only reaches 56.000, indicating that only 14 of the 26 industries are related to it. Therefore, in terms of point and center degree, although the overall performance of innovation correlation between industries is relatively balanced, the correlation level is not high.

According to the performance of betweenness, the mean value is 3.808, and there are 10 industries above the mean value. Among them, C26, C40, D46, and C39 are the highest, indicating that these industries have a strong control over other industries in the innovation network and play a core role in network "intermediary" and "bridge." This is also in line with China's strategic goal of integrating big data, artificial intelligence, and real economy into the intelligent manufacturing industry based on the new generation of information technology industry. The betweenness of B07 and D44 is 0, indicating that these two industries cannot control any other industries and are on the edge of the whole network.

From the perspective of near-center performance, the mean value is 53.183, and there are 14 industries above the mean value. The top several industries are C40, C39, C34, C31, C30, etc. Similar to the ranking of point center degree and intermediary center degree, it indicates that these industries have a short "distance" from other industries in the network. These industries play the role of "bridge" and also take a "central" position, which can facilitate the exchange of innovative information with other industries.

In general, the performance of each industry in the three dimensions of individual centrality is not very different. High-end equipment manufacturing, new materials industry, and new-generation information technology industry occupy the center of the network. The performance of the new energy industry was the worst, followed by the energy conservation and environmental protection industry. In order to make breakthroughs in core technologies in key fields, China has actively cultivated strategic emerging industries, especially the high-end equipment manufacturing industry and the new-generation information technology industry, so as to place them at the core of the whole innovation network [53]. However, it can be seen from the measurement of in-degree and out-degree that the spillover effect of these industries is poor and their driving effect on other industries needs to be further strengthened. In order to implement the concept of green development, government departments should focus on and improve the radiation effect of energy conservation and environmental protection industry.

4.3. Block Model Analysis

From the perspective of location, the total number of strategic emerging industry innovation networks in 2018 was 146. From the analysis results of plate association effect in Table 3, it can be seen that there are 98 intra-plate association numbers and 48 inter-plate association numbers, and the actual internal relationship ratio is greater than the expected internal relationship ratio. The analysis result of block model can be seen in Table 8.

Table 8. The analysis result of block model.

Analysis Indicators		**Analysis Result**
Positional analysis	Plate I	Broker plate plays a link role in the network.
	Plate II	The main overflow plate in the network is the first engine of innovation for the rest of the plate.
	Plate III	The bidirectional overflow plate in the network is the second engine of innovation for the remaining plates.
	Plate IV	The main income plate in the network causes it to rely on the spillover effect of other plates.
Hierarchical analysis	Plate I	Although there is an overflow relationship with other plates, its density is far from that of the whole network, and almost independent of the whole network.
	Plate II	This can cause the linkage effect of the innovation network, especially with the main plate IV benefit correlation effect is obvious.
	Plate III	This can cause the linkage effect of the innovation network, especially with the main plate IV benefit correlation effect is obvious.
	Plate IV	There are only three spillover relationships outside the plate, most of which are concentrated inside the plate.
Integral analysis	The spillover effect between the plates is not obvious, but more shows the characteristics of "reflexive" aggregation subgroup, and the innovation association has the characteristics of cross-industry clustering.	
Block model analysis	Energy conservation and environmental protection industries and new energy industries are mostly independent of the overall network. Although the development of new material industry and new generation information technology industry has made some progress, its application ability and radiation effect need to be improved.	

This indicates that the spillover effect between plates is not obvious and shows the “reflexive” condensed subgroup characteristics. Therefore, the roles of each section are relative rather than absolutely matched according to the main characteristics specified above. Plate I receiving other plate number of overflow of eight, overflow to the other plate number to 3, the relationship between plates is more suitable for brokers. Most of these sectors come from the energy conservation and environmental protection industry, which mainly receives the relationship between the high-end equipment manufacturing industry of other sectors. At the same time, it has an impact on the energy conservation and environmental protection industry in other sectors and plays a role of connecting link in the network. Plate II overflow relationship for 17 to other plates, obviously redundant relationship to receive the rest of the plate number 6. Therefore, it is a typical main overflow plate. Although the industry of this plate has the least number of members, the overflow effect is obvious. These industries can provide raw materials or precision instruments and other resources for other sectors, so this sector is the first engine of innovation for other sectors. The number plate III sent internal relationship is 38, and the external relationship number is 25. However, they do not receive the rest of the plate relationship, which is a typical two-way overflow plate. The industry of this sector can provide infrastructure and special equipment support for some industries of other sectors without being affected by other sectors, so it is the second engine for innovation of other sectors. The number plate IV relationship to receive the rest of the industry is 19, significantly more than the spill over into the rest of the plate number 3. Internal communication is very frequent, so it is a typical main income plate. This section mainly involves the new material industry and the new generation of information technology industry. This plate should have been able to send more relations to the rest. However, due to the unreasonable network structure of strategic emerging industries, they are more dependent on the spillover effect of other sectors.

From Table 4 and Figure 5, it can be found that many industries of the same strategic emerging industry are in different sectors, and the innovation correlation has the characteristics of cross-industry clustering. Compared with the plate interior, the linkage effect between plates is insufficient. Plate I has an overflow relationship to the rest of the plate, but the density and overall network density is almost independent of the whole network. Plate I mostly comes from the energy conservation and environmental protection industry and new energy industry, explain our country present stage needs to be set up to promote the market mechanism of green innovation. Plate II and plate III as overflow plate, can cause the linkage effect of the innovation network, especially with the main plate IV benefit correlation effect is obvious. Plate IV industries, C28, C31 microcomputer and C33 all come from the new material industry, C39 comes from a new generation of information technology industry. There are only three spillovers to the outside of the plate, most of which are concentrated in the inside of the plate, indicating that China has made some progress in the development of new materials industry at the present stage. However, its application ability needs to be improved, so it is necessary to promote the integration of the two industries to the collaborative application of the industrial chain.

4.4. Analysis of the Effect of Network Structure Characteristics on Industry Attributes

According to the Hausman test results, the three panel regression results all support random effects. In order to clearly demonstrate the effect of network structure on industry attributes. The spillover effects of centrality degree, betweenness and closeness are summarized as shown in Table 9.

Table 9. Analysis result of network structure characteristics on industry attributes.

	Analysis Indicators		
Independent Variables	**Regression Coefficient**	**Significant**	**Analysis Result**
Centrality degree	−	10%	The improvement of centrality degree in the innovation network of strategic emerging industries is not conducive to the enhancement of innovation output.
Betweenness	+	N	The improvement of the betweenness of innovation network in strategic emerging industries may promote the innovation output of various industries, but the effect is not significant.
Closeness	+	10%	The improvement of the innovation network closeness of strategic emerging industries has an obvious promoting effect on the innovation output of the industry.

Specifically, it can be seen from Table 5 model 1 that the regression coefficient of centrality degree is negative and passes the significance test at the level of 10%. It indicates that the improvement of centrality degree in the innovation network of strategic emerging industries is not conducive to the enhancement of innovation output. The improvement of degree centrality means the establishment of more connections with other industries, including the absorption effect of innovation in other industries and the spillover effect of innovation to other industries. When the spillover effect is greater than the absorption effect, the marginal innovation cost of the industry increases, which inhibits the innovation output of the industry. Moreover, if both the point-in degree and point-out degree of an industry are 5.615 and the number of related industries is 8.923, then the number of industries related by two-way strong relationship is only 2.307. The strong relationship of two-way correlation can make the innovation flow between industries smoother, communicate with each other more fully, and promote the collaborative innovation between industries. At this time, the innovation network is because the weak relationship is far more than the strong relationship, resulting in a serious asymmetry of information. It aggravates the cost of innovation so that the centrality degree has a negative impact on the output of innovation. It can be seen from model 2 that the regression coefficient of betweenness is positive but fails the significance test. It indicates that the improvement of the intermediary degree of innovation network in strategic emerging industries may promote the innovation output of each industry, but the effect is not significant. The reason is that the industry can enhance its ability to control resources in the network through the improvement of betweenness. Adjacent ends of the industry can produce a stronger driving effect on the industry. However, the positive effect is not significant due to the existence of industries with 0 intermediary center degree in the network, and the data is not normally distributed. According to model 3, the regression coefficient of closeness is positive and passes the significance test at the level of 10%. It shows that the improvement of the innovation network near the center of strategic emerging industries has an obvious promoting effect on the output of industry innovation. The improvement of closeness has narrowed the "distance" between the industry and other industries. It can save the transaction cost of innovation and also reduce the loss and deviation of information transmission, which can promote the innovation output of the industry to some extent [54].

In general, there is still a lot of room for improvement in the network structure of strategic emerging industries. The irrationality of the correlation method leads to the increase of degree centrality, which inhibits the output of industry innovation. Therefore, the adjustment of industrial structure should pay attention to both the degree of integration between industries and to the way of integration. In addition, it is necessary to increase the proportion of strong correlation in the network, especially for the industries with low betweenness and closeness, such as D46, B07, C13, etc. To enhance the radiation effect of core industries, technological innovation can improve product quality and play a positive role in reducing capacity and inventory.

5. Conclusions and Implications

Based on the theory of industry correlation and the thought of gravity model, this paper studied 26 industries supported by strategic emerging industries. Variables such as innovation quality and industry distance are introduced to construct an innovation network of strategic emerging industries based on industry correlation. Using the method of social network analysis, this paper studied the overall structure development trend, individual network characteristics, and block model of China's strategic emerging industry innovation network. Furthermore, the influence of network structure on the innovation level of various industries was further analyzed.

The main research conclusions are as follows: (1) From the perspective of the overall network characteristics, the innovation network of China's strategic emerging industries is in a slight downward trend of low density. The trend turned in 2017 due to the adjustment of industrial policies. In 2018, the density of the network increased slightly, and the rigid hierarchical structure was weakened. The stability of the whole network has been enhanced, but there is still much room for improvement of the overall level of network correlation. (2) From the perspective of individual network characteristics, although the innovation relationship between strategic emerging industries has obvious network characteristics, the inter-industry heterogeneity is significant. In addition, there is a serious imbalance between point-in degree and point-out degree in most industries, and the proportion of strong correlation is too low. High-end equipment manufacturing, new material industry and new-generation information technology industry occupy the center of the network, but their spillover effect to other industries is poor. The performance of the biological industry and the new energy automobile industry is at the middle level, while the performance of the new energy industry as a whole is the worst, followed by energy conservation and environmental protection industry. (3) It can be seen from the results of block model analysis that the innovation association of strategic emerging industries in China has the characteristics of cross-industry clustering. Moreover, the linkage effect between plates is insufficient, showing the characteristics of "reflexive" condensed subgroup. Among them, plate I focused on energy conservation, the environmental protection industry, and new the energy industry, plate as brokers. However, the relationship between its overflow and reception is small, and the density between it and other plates is less than the average density, which is almost independent of the whole network. The main overflow sector is the smallest, with only three members from three different industries: energy conservation and environmental protection, high-end equipment manufacturing and new materials. Bidirectional overflow plate contains all the biological industry, new energy automobile industry. The main beneficiary sectors are new materials industry and new generation of information technology industry, while high-end equipment manufacturing industry is distributed in various sectors. (4) From the effect of structural characteristics on attribute performance, it can be seen that the unreasonable connection mode of innovation network in China's strategic emerging industries leads to the improvement of centrality degree, which is not conducive to the output of industrial innovation. However, by improving the betweenness and closeness of the industry in the network, the innovation output of each industry can be positively affected to a certain extent.

The research results of this paper have certain theoretical significance and practical value. From the perspective of theoretical significance, the expansion of the gravity model to the innovation network of strategic emerging industries has enriched the theoretical research on the innovation network of strategic emerging industries. From the perspective of practical value, based on the main research conclusions, this paper proposes the following countermeasures and suggestions for the formulation of industrial policies: (1) It is necessary to clearly recognize that the network structure of China's strategic emerging industries is still in low density, high level, and high network efficiency. The government has further explored new channels for promoting technology connection through product consumption by actively building innovative links between new models and new forms of business. While improving the overall density of the network, it can also enhance the stability of the innovation network. (2) The government should give full play to the core role of high-end equipment manufacturing and the new-generation information technology industry in the network. Especially in order to realize the development goal of industrial green innovation, the government should pay more attention to its radiation effect on energy conservation and environmental protection industry, new energy industry and new material industry. At the same time, the government should establish a market mechanism to promote the application of green innovation, and truly give play to the basic role of new material industry such as "industrial food." (3) The formulation of industrial policy should also pay attention to the characteristics of cross-industry clustering and the linkage effect between plates. It should be refined according to the different roles of the sectors in which the industry is located, so as to avoid the "one-size-fits-all" industrial policy for an emerging industry. By strengthening the innovation quality of overflow plate, it can indirectly affect the innovation output of revenue plate and broker plate. (4) While paying attention to the correlation degree of industrial innovation, the government should also pay attention to the correlation way. Improving the correlation situation of the existing innovation network is a key problem to be solved. Through the establishment of two-way correlation channels, the proportion of strong correlation in the network is increased. By improving the betweenness and closeness of the marginal industries, the government can narrow the innovation and development gap between industries and strengthen the collaborative innovation and integration of the industrial chain.

Although this paper has some contributions in theory and practice, it still has some shortcomings. On the one hand, this paper only adopts quantitative method for innovative network analysis and does not introduce qualitative case study for further analysis. On the other hand, this paper does not consider the influence of geographical factors such as culture and political preference on innovative network research. Therefore, it is worthwhile to study the development of innovation network in different countries. In terms of research methods, the fuzzy logic method is an important method applied to the research of innovative network. These problems need to be further discussed in the follow-up research.

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Appendix A

Symbol	Connotation	Symbol	Connotation
Y_{ij}	The innovation attraction between industry i and j industry	E_i/E_j	The innovation output of i and j industries, as measured by the number of patent applications
P_i/P_j	The input of innovative personnel measured by the equivalent of full time R&D personnel	G_i/G_j	The investment intensity of innovation capital measured by the ratio of internal expenditure of R&D expenditure to main business income
K_{ij}	The contribution rate of industry i in the innovation association between industry ij	D_{ij}	The industry distance
r	The friction coefficient	X_i	The total output of the industry i
F_i	The total amount of the industry i flowing directly to the final consumer and capital formation	Z_i	The part consumed by other industries as intermediate inputs in the output of the industry i
a_{ij}	The direct consumption coefficient	V_i	The weighted average position of industry i in the industry chain
I	Unit matrix	A	A consumption matrix consisting of direct consumption coefficients
F	$N \times 1$ matrix of F_i	U_i	The downstream position of industry i in the industrial chain
ρ	Network density	n	The actual number of relationships
R	Network relevance	m	The number of unreachable point pairs in the network
GH	Network level	S	The logarithm of points that are symmetrically reachable in the whole network
$\max(S)$	The logarithm of points that i can reach j or j can reach i	GE	Network efficiency
e_k	The number of redundant lines in component k	$\max(e_k)$	The number of lines in component k that are most likely to be redundant
E	The number of redundant lines in the whole network	$\max(E)$	The maximum possible number of redundant lines in the whole network
C_{RB}	Betweenness	g_{jk}	The shortcut number between point j and point k
$g_{jk}(i)$	The number of shortcuts that point i takes between point j and point k	$b_{jk}(i)$	The ability of point i to control the communication between point j and point k
C_{RP}	Closeness	d_{ij}	The shortcut distance between point i and point j

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